SOLIDIFICATION UNDER ZERO GRAVITY- A LONG DURATION EXPOSURE FACILITY (LDEF) EXPERIMENT FOR AN EARLY SPACE SHUTTLE MISSION

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SOLIDIFICATION UNDER ZERO GRAVITY - A LONG DURATION EXPOSURE FACILITY (LDEF) EXPERIMENT FOR AN EARLY SPACE SHUTTLE MISSION

Semi-Annual Report to National Aeronautics
and Space Administration Grant NSG 1136

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ABSTRACT

The preliminary design of two series of simple experiments the objectives of which are to determine the effect of an absence of gravity on (i) the general morphology of the structure, (ii) location of ullage space, and (iii) magnitude of surface tension driven convection, during the solidification of several metallic and non-metallic systems is described. Details of the investigative approach, experimental procedure, experimental hardware, data reduction and analysis, and anticipated results are given. In addition a work plan is provided.

TABLE OF CONTENTS

1. SCOPE

The present report is a statement of work carried out under National Aeronautics and Space Administration Grant NSG 1136 entitled "Long Duration Exposure Facility (LDEF) Experiments for Early Space Shuttle Missions" and covers the working period January 15, 1975 to August 15, 1975.

2. INTRODUCTION

Approximately two years ago, several experiments concerning the effects of a space environment on the melting-freezing behavior and frictional characteristics of materials were proposed by the principal investigator. These experiments formed a portion of a total of seventeen suggested for possible conduct aboard the early flights of the proposed space shuttle. A brief description of the experiments was given in a document entitled, "Phase A Planning Document", prepared by Dr. J. J. Wortman of the Engineering Division of the Research Triangle Institute for the National Aeronautics and Space Administration.

Tentative approval of the experiments led to the award by the National Aeronautics and Space Administration of a one year contract beginning on January 15, 1975 for the sum of $9,998.58. Work on the grant involves the generation of background information and data of value in the future design, construction and testing of the proposed experimental packages.

More recent screening of candidate experiments by the National Aeronautics and Space Administration has led to the selection of a portion of the proposed experiments concerned with a study of the melting-freezing behavior of materials in a space environment as being feasible for conduct aboard an early space shuttle flight, where technical simplicity is essential. A presentation of the objectives, investigative approach, anticipated results and implications was given to Dr. Smiley at NASA Headquarters, Washington, D. C.

on March 6, 1975 and to LDEF Project personnel at NASA Langley Research Center, Hampton, Virginia on May 20, 1975. Subsequently, the principal investigator was requested to submit a proposal to allow final selection of the first LDEF experiments. Much of the information contained in that proposal was generated under the present grant and is documented in this report.

3. OBJECTIVES

The environment of the orbiting LDEF provides a very unique opportunity for studying phenomena associated with the behavior of materials under conditions which previously were unobtainable. Perhaps one of the most interesting and important natural phenomena is that of solidification which is associated with the liquid⇄solid phase change.

The basic objective of the proposed experiment is to determine whether or not solidification of materials (metals and nonmetals) in a ZERO-G environment is different from that occurring in a ONE-G environment. In particular, the absence of gravity on (i) the general morphology of the structure, (ii) the location of ullage space and (iii) the magnitude of surface tension driven convection will be studied.

For gravitational environments in the range from ZERO-G to ONE-G interatomic forces in materials are greater than the gravitational forces to the point where differences in the mechanisms of solidification and fine scale structure would not be anticipated. However, it is believed that a reduction in the magnitude of the gravitational forces can lead to changes in the location of the ullage space and the onset of surface tension driven convection. The ullage space is that space which must be provided to allow for contractions and expansions of materials during the melting/freezing process. In a ZERO-G environment there will be an absence of natural convection because of the lack of buoyancy forces. However, convection driven by

surface tension forces could be appreciable. Convection driven by surface tension forces is known as Marangoni flow.

Some work has been conducted in several previous space missions concerning the solidification of materials in a space environment. However, the work is very limited and an understanding of the phenomena involved has not yet been produced A critical review of this work will be presented in the final report.

The proposed experiments, although of necessity technically simple, will provide a very unique opportunity to generate qualitative and quantitative information which will lead to an advancement in our understanding of the basic principles of solidification and provide a firm basis for the development of more sophisticated experiments which may lead to the generation of invaluable data at a later date. It is believed also that the aforementioned experiments can provide data which is of more immediate and direct practical value. Recently, cooling/heating devices (thermal capacitors) have been developed based on the use of an encapsulated material (PCM) which is forced to undergo a phase change (solid⇄liquid). The device absorbs heat from an external medium when the phase change material (PCM) melts and rejects heat to the medium when the phase change material solidifies. The heat absorbed or rejected is, of course, the latent heat of fusion of the phase change material.

Thermal capacitors have been used for temperature control and heat storage on the Lunar Roving Vehicle (LRV), Skylab I and Apollo's 15, 16 and 17. However, it is believed that potential problems may develop if solidification in the space environment is not controlled. For example, if the ullage space forms adjacent to the channel carrying the externally circulating medium then heat transfer will be seriously impaired and the efficiency of the capacitor reduced. Under normal gravitational conditions (ONE-G) the

position of the ullage space can be controlled by suitable orientation of the capacitor However, such control is not possible in a zero gravity environment In the absence of gravity it is important to know how and where the ullage space forms so that future capacitor designs can be improved. Similarly, capacitor performance may be changed radically should surface tension driven convection become an important mode of heat transfer. Mort thermal capacitor designs are based on conduction models of the heat transfer process. Clearly, the proposed experiments could provide valuable information of direct use in the design of thermal capacitors for future space missions.

In the proposed experiments it is hoped to show that some control over the location of the ullage space can be established by selection of the appropriate relative interfacial energy between the test material (liquid) and container. It is hoped also to show that surface tension driven convection can be generated and controlled by control of the temperature gradient and hence, local surface tension along an interface (liquid-vapor) Elaboration of the principles and techniques involved in the design of the experiments is given in Section 4 Experimental Hardware is described in Section 5. Method of Data Analysis and Anticipated Results are described in Sections 6 and 7, respectively A complete work plan for the design, construction and testing of the experimental package is given in Section 8.

4. INVESTIGATIVE APPROACH

4.1 Concepts of Experiments

It is proposed to conduct two different but related series of experiments. One experiment will be concerned with an investigation of the general morphology of the structure produced by solidification of a liquid. The other experiment will be concerned with an investigation of the magnitude of surface tension driven convection Both experiments will be conducted, of

course, in a zero gravity environment. The schematic arrangement for the experiments is given in Figure 1

4.1.1 General Morphology Studies

In the first series of experiments a small sample of each test material with a volume in the range from one to three cubic centimeters will be press-fitted into a lined, cylindrical stainless steel container with a height to diameter ratio of approximately unity. The containers will be filled with argon at normal atmospheric pressure and sealed. The size of the containers will be such that there will be approximately seventy percent ullage. The containers will be attached securely to wire wound resistance heating units (furnaces) (Figure 2). The capability of the units will be such that sufficient heat can be produced to melt the sample. For testing low melting point translucent materials,,the containers will be made from a high melting point transparent plastic so that visual observation of the total morphology of the structure can be made after solidification. Heating will be from "below" so that stability will be maintained until test sample is completely melted.

The linings of the container and/or actual test materials will be selected to meet two broad requirements, namely; (1) test material wets container (low relative interfacial energy), and (2) test material does not wet container (high relative interfacial energy). Three identical cells for each material will be made. This scheme enables the effects of variations in the relative interfacial energy between container and test material on the general morphology and location of ullage space to be studied.

In the initial proposals for the experimental package it was intended to select materials from systems possessing widely different physical and chemical characteristics so that a comprehensive broad based program of activity could be established. The tentative systems identified included low

melting point pure metals, low melting point immiscible alloys, low melting point eutectiferrous alloys, pure paraffin hydrocarbons and paraffin hydrocarbon mixtures However, it was suggested that the scope of the proposed activity be reduced to fit within the revised total scope and objectives of the LDEF mission Accordingly, it is now proposed to select low melting point pure metals and either pure paraffin hydrocarbons or pure fatty acids as the systems for investigation The melting points of the materials will be kept in the range from 50°C to 300°C to keep power requirements and design difficulties at a minimum Hopefully, other systems can be examined at a later date.

A thorough review of the literature has been conducted and numerous materials from each of the aforementioned systems identified. These materials along with appropriate mechanical, physical and thermal property data will be given in the final report Also given will be the final selections of the candidate materials for experimentation

4.1.2 Convection Studies

In the second series of experiments small samples of each test material will again be press fitted into lined stainless steel containers and sealed under an atmosphere of argon as in the previous series of experiments. However, here the ullage space will be reduced to approximately 25% and the diameter to height ratio of the cylinder will be of the order of two in order to provide a large solid (liquid)-vapor interface. In addition, a small platinum wire heating element will protrude from one end of the cylinder into the ullage space The active (hot) end of the element will be located approximately 5mm above the solid surface of test sample (Figure 3). The materials finally selected for the studies in Section 4 1.1 described above will be used in this series of experiments However, three identical cells for each material will be made It is hoped that with this scheme investigation

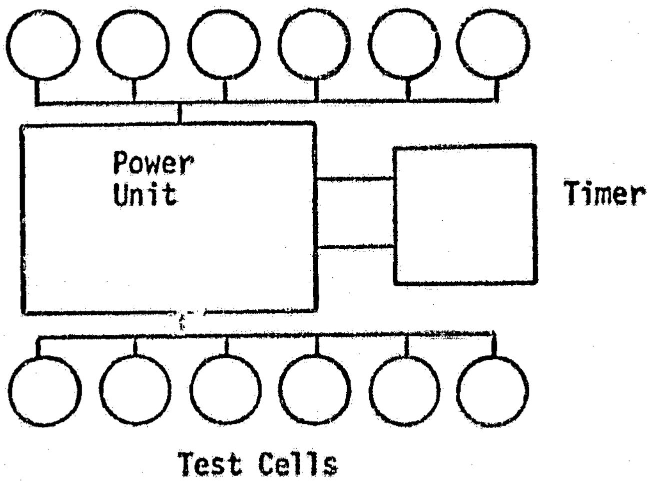


FIGURE 1. EXPERIMENTAL ARRANGEMENT (schematic).

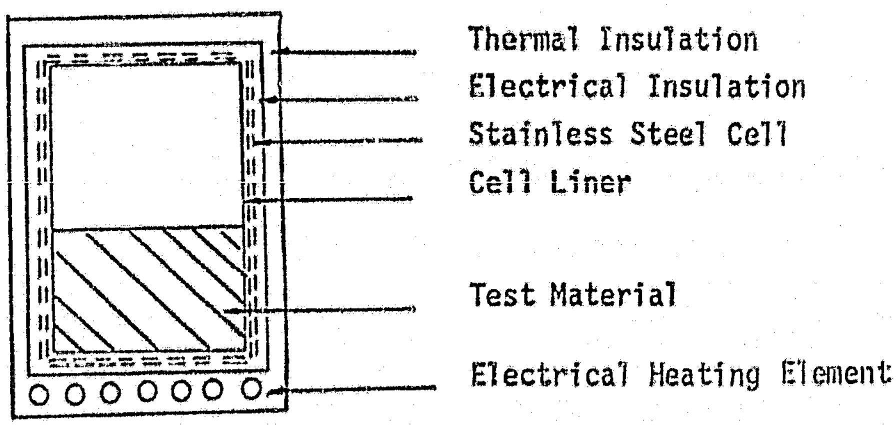


FIGURE 2. TEST CELL (i) (schematic section).

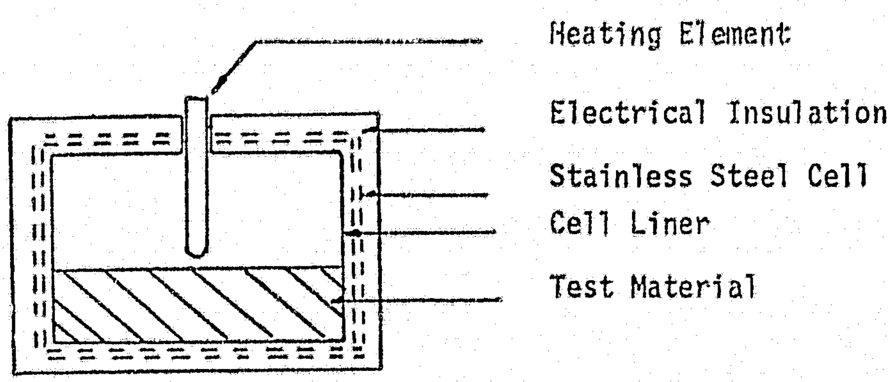


FIGURE 3. TEST CELL (ii) (schematic section).

of the effects of variations in interface tension produced by interface temperature gradients on convection can be studied for liquid-vapor interfaces.

4.2 Experimental Procedure

The experimental procedures to be used are particularly simple and therefore ideally suitable for conduct aboard the first several flights of the space shuttle

For the first series of experiments [(4.1.1) above] the test materials will be heated from "below" to produce complete melting. Each sample will be held in the liquid state for prescribed but different periods of time then allowed to cool to ambient temperature. For the second series of experiments [(4.1.2) above] a current will be passed through the platinum wire heating element to produce radiant heating of the center most portion of the "upper" surface of the test material. Each sample will be heated for prescribed but different periods of time then allowed to cool to ambient temperature. It is important to state here that the test samples will not be melted completely. The unmelted material will serve to stabilize the melted material because of the surface tension forces generated at the solid-liquid interface.

In the initial experimental design it was proposed that power consumptions and temperature distributions within the test cells be measured and recorded continuously as a function of time during the real time life of the experiment. However, recent restrictions have led to the elimination of this aspect of the program. Thus, in flight quantitative data will not be generated. The experimental results will be generated from post flight sample characterization which will be described in Section 6 of this report. Consequently, assistance from the Shuttle crew and Ground Support personnel will not be needed other than that normally required for delivery, installation and retrieval of the experimental package.

5. EXPERIMENTAL HARDWARE

5.1 Physical Characteristics

The experimental package will consist of twelve test cells as describ-ed in a previous section, a battery power pack and timer to initiate the experiment. The package will be rectangular in section measuring approximately 20 in. x 30 in x 6 in ($2\ ft^3$) and weigh approximately 18 lbs.

The power system will consist of a DC battery pack to furnish power for melting the test samples and driving the timer module. A review of the technical literature has been conducted and a number of manufacturers have been contacted concerning the characteristics and availability of the various types of DC power supplies suitable to drive the present system. Choice of a power supply has not been made at this time. However, it is anticipated that either silver-zinc or nickel-cadmium type batteries will be used. Preliminary calculation with the revised experimental profile indicates that approximately 60 Btu total heating capacity will be required. Data recording systems are not required with the revised experimental profile

The experimental package will be designed such that it will neither produce, nor be susceptible to degradation through electromagnetic interference contamination, acoustic radiation and mechanical vibration over the levels anticipated during ground handling, launch, space exposure and recovery. The only active components in the experimental package are the battery power pack and timer unit

The test materials and materials used in the construction of the experimental package will be selected to be compatible with the temperature profile provided in the Space Shuttle Users Guide. However, use of a number of low melting point materials (as yet unspecified) is planned for the solidification experiment It is anticipated that the maximum permissible

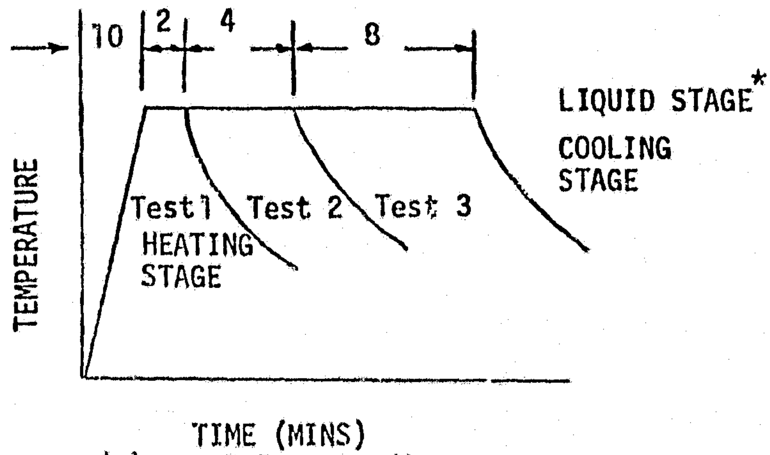
environmental temperature will be 150°F. This limit can, of course, be increased by a change in test material.

Special electrical, mechanical or control requirements are not required. The experiment will be initiated by a signal from an electrical timer module after release of the LDEF from the shuttle. The approximate temperature-time histories of the two categories of experiments are given in Figure 4. It can be seen that the total duration of the experiments is approximately eighty minutes. Upon final solidification the experiments will remain dormant until recovered. Setting of the timer to its sequence will be required prior to launch. It is anticipated here that installation of the experimental package on board LDEF and timer initiation will be undertaken by ground support crews.

The location of the experimental package on LDEF is not critical. Each sample module will be hermetically sealed and thermally insulated. However, it is desirable that there be a minimum of spacecraft attitude change during actual solidification of the test samples to avoid the possible generation of disturbances within the solidifying materials. The experiment will be attached to the experiment tray by means of a bolted joint employing reusable selflocking fasteners.

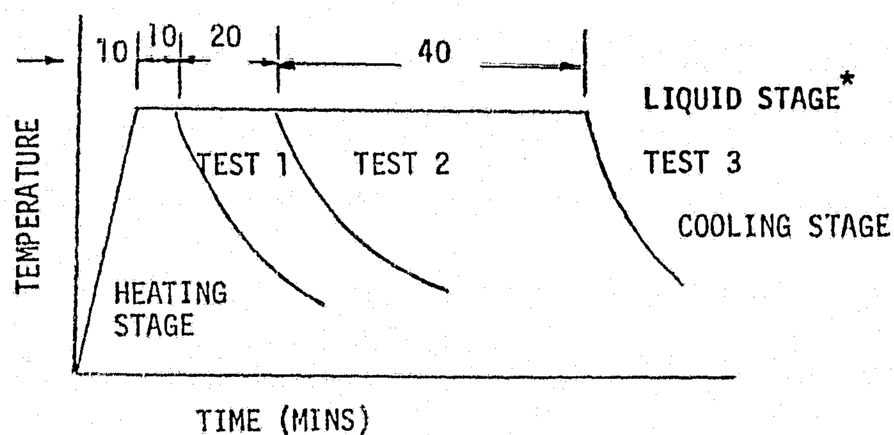
5.2 State of Development

A straightforward engineering design effort is required to select materials and to design the timer and heater/power modules. Familiar, well characterized materials, components and designs will be utilized. Hardware does not exist. However, materials and components are available on an off-the-self basis. Many similar experiments have been completed in the laboratory. Work on the present grant has shown that most of the basic information required to design and construct the experimental package is available in the



(i) Morphology Studies

*Liquid stage temperature to depend on material selection



(ii) Connection Studies

*Liquid stage temperature to depend on material selection

FIGURE 4. SCHEMATIC TEMPERATURE-TIME PROFILES. (not to scale)

technical literature. This information is currently being gathered and reduced to a usable form. Preliminary calculations have been made concerning overall size and weight of experimental packages and overall power requirements of proposed experiments. At the present time extensive mechanical and thermal property data has been gathered for a wide range of metallic and nonmetallic candidate test materials. The process of final selection is underway.

The need for supporting studies is not anticipated. However, it is recognized that it may be necessary to generate some information concerning relative interfacial energies between a variety of metallic and nonmetallic pairs before final materials selection is made, should such data be unavailable in the technical literature. This information, if needed, will be generated in the remaining grant period.

6. DATA REDUCTION AND ANALYSIS

Convection currents in fluids are usually driven by gravity in a ONE-G environment. However, gravity is not the only force capable of inducing fluid flow. Surface tension, interfacial tension, and volume changes associated with phase transformations (solid$\rightleftarrows$liquid) can serve as dr ing forces for fluid flow under the appropriate conditions.

Fluid flow caused by surface tension gradients is called Marangoni flow. If a liquid surface (liquid-vapor interface) is subjected to a temperature gradient then a surface tension gradient will be induced because surface tension is a function of temperature. Liquid will flow along the surface from regions of low surface tension (hot region) to regions of high surface tension (cold region). The velocity of fluid flow decreases with increasing depth beneath the surface: the depth of the disturbed region depending upon many hydrodynamic factors. Concentration gradients can induce

also surface tension driven convection because surface tension is a function of chemical composition.

In a ZERO-G environment gravity driven convection will be absent and surface tension driven convection should predominate. The present experiments have been devised to demonstrate the importance of surface tension in such an environment. The requirements of simplicity have precluded the generation of "on board" quantitative data. Data will be gathered by post flight analysis of tested samples.

Although the proposed experiments have been divided up into two categories they are in fact closely related. For both series of experiments the solidified test samples will be subjected to extensive post flight analysis. The analysis will consist essentially of sample characterization using a wide range of diagnostic techniques. The cylinders or cells containing the test samples will be examined first by X-Ray radiography then sectioned to expose the solidified surfaces. The surfaces will be examined using optical and scanning electron microscopy to determine both the macroscopic and microscopic geometry and characteristics of the surface. Next, the overall general shape of the solidified materials will be obtained by additional sectioning along planes parallel and perpendicular to the cylinder axis. The sections will be prepared in the usual way and examined in detail using optical microscopy to characterize thoroughly the general crystallography of the microstructure. Factors such as grain size, grain shape and grain orientation will be determined quantitatively. The samples will be examined also for the presence of general porosity, microporosity, and cracks. If detected their appearance, size, and distribution will be determined quantitatively by standard procedures. Selected areas of the specimens will be examined using X-Ray diffraction methods to generate additional information concerning

the fine scale structure of the solidified materials. The interface between the container and solidified material will be examined critically using optical microscopy and X-Ray microprobe analysis to determine the nature of the interface.

7. ANTICIPATED RESULTS

In the experiments described under general morphology studies [(4.1.1) above] it is anticipated that changes in the solid-liquid interfacial energy brought about by changes in the characteristics of the cell liners will produce ultimately differences in the distribution of ullage space. For example, for low relative interfacial energies (wetting) surface tension forces may permit, in the absence of gravity, migration of the liquid test material around the walls of the cell leaving the ullage in the vicinity of the center (Figure 5a). For high relative interfacial energies (nonwetting) the liquid may tend to exist essentially detached from the cell walls (Figure 5b). However, it is conceivable that small perterbations in the LDEF attitude may induce the liquid to break up producing a globular structure with considerable porosity. The conduct of several experiments of different durations will enable the effect of time on the morphology of the structure of the solidified material to be determined. However, it is anticipated that this effect will be negligible (unless instabilities occur). The complete post flight microstructural analysis of samples should enable flow patterns and flow characteristics generated within the liquid which led to the final structure to be identified.

In the experiments described under Convection Studies [(4.1.2) above] radiant heating is used to produce a liquid pool in the center of the "upper" surface of the test sample. It is anticipated that the temperature at the center of the liquid pool will be considerably higher than that at the edge

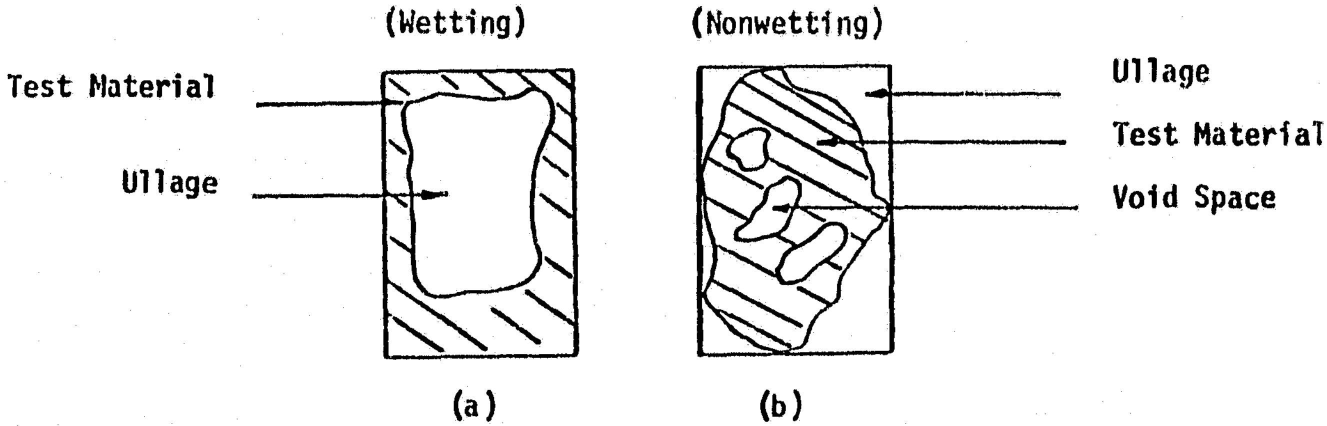


FIGURE 5. POSSIBLE LOCATION OF ULLAGE SPACE.

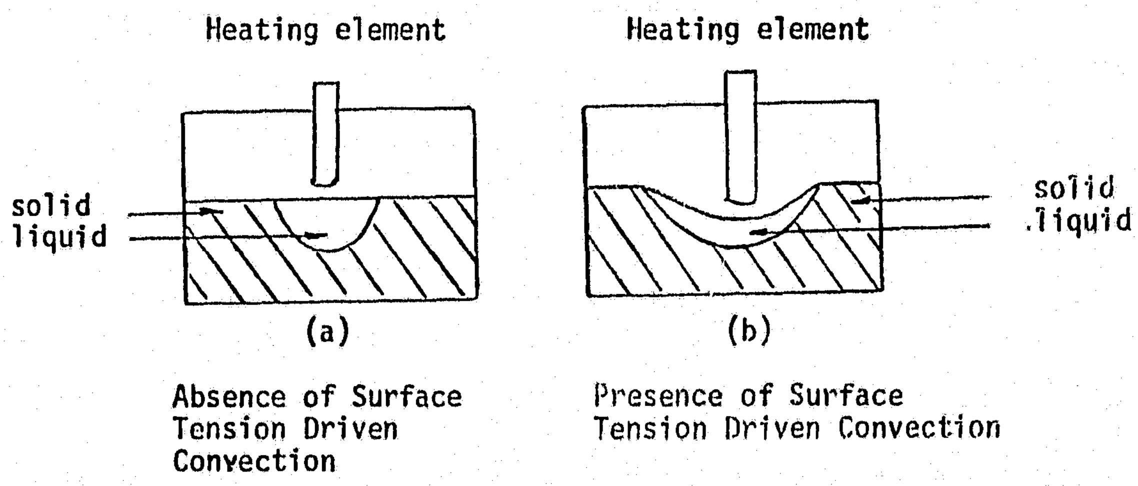


FIGURE 6. SURFACE TENSION DRIVEN CONVECTION.

adjacent to the unmelted material. The temperature gradient will change the liquid-vapor interfacial energy locally and induce surface tension driven convection which should change the profile of the solid-liquid interface. If convection is present then the rate of heat transfer and melting will be increased. The result should be an increase in the maximum diameter of the pool [Figure 6(a)(b)] Examination of the structure of the sectioned samples will enable the extent of melting in a particular test (solid-liquid interface) to be determined. It is anticipated that the extent of melting due to convection should increase with an increase in time. The position of the solid-liquid interfacial boundaries (profile) determined from post flight specimen examination will be compared with the calculated position of the solid-liquid interfacial boundaries (profile based on a conduction [no convection] model of the melting process). It is hoped that the differences in shapes of the boundaries can be attributed to convection currents in the melt driven by surface tension.

8. WORK PLAN

8.1 Concepts of Work Plan

Early space shuttle missions will involve many widely different experimental packages within each payload. Each of these packages will be conceived, designed, constructed, and tested at sites remote from the National Aeronautics and Space Administration, Langley Research Center. Clearly, it is of the utmost importance that experimental packages arrive at the Center at the prescribed time for the overall success of the missions. A work schedule has been devised to assure efficient utilization of the time, funds, material and personnel resources and to provide the National Aeronautics and Space Administration with an estimate of the time required to produce the proposed experimental package.

8.2 Management

The limited nature, size and scope of the proposed activity is such that complex managerial arrangements and plans are not required.

Dr. Bailey, Professor of Mechanical and Aerospace Engineering will serve as principal investigator and assume administrative responsibility for the project. He will have responsibility also for sample material selection, fabrication and post flight data analysis. Dr. Whitfield, Professor of Mechanical and Aerospace Engineering will serve as co-principal investigator and assume responsibility for hardware design, development, and testing.

A number of graduate students will assist the principal and co-principal investigators with details of the experimental design, preparation of drawings of hardware, hardware acquisition, testing and data reduction and analysis. It is anticipated that their contributions will form the basis of theses in partial fulfillment of advanced degrees.

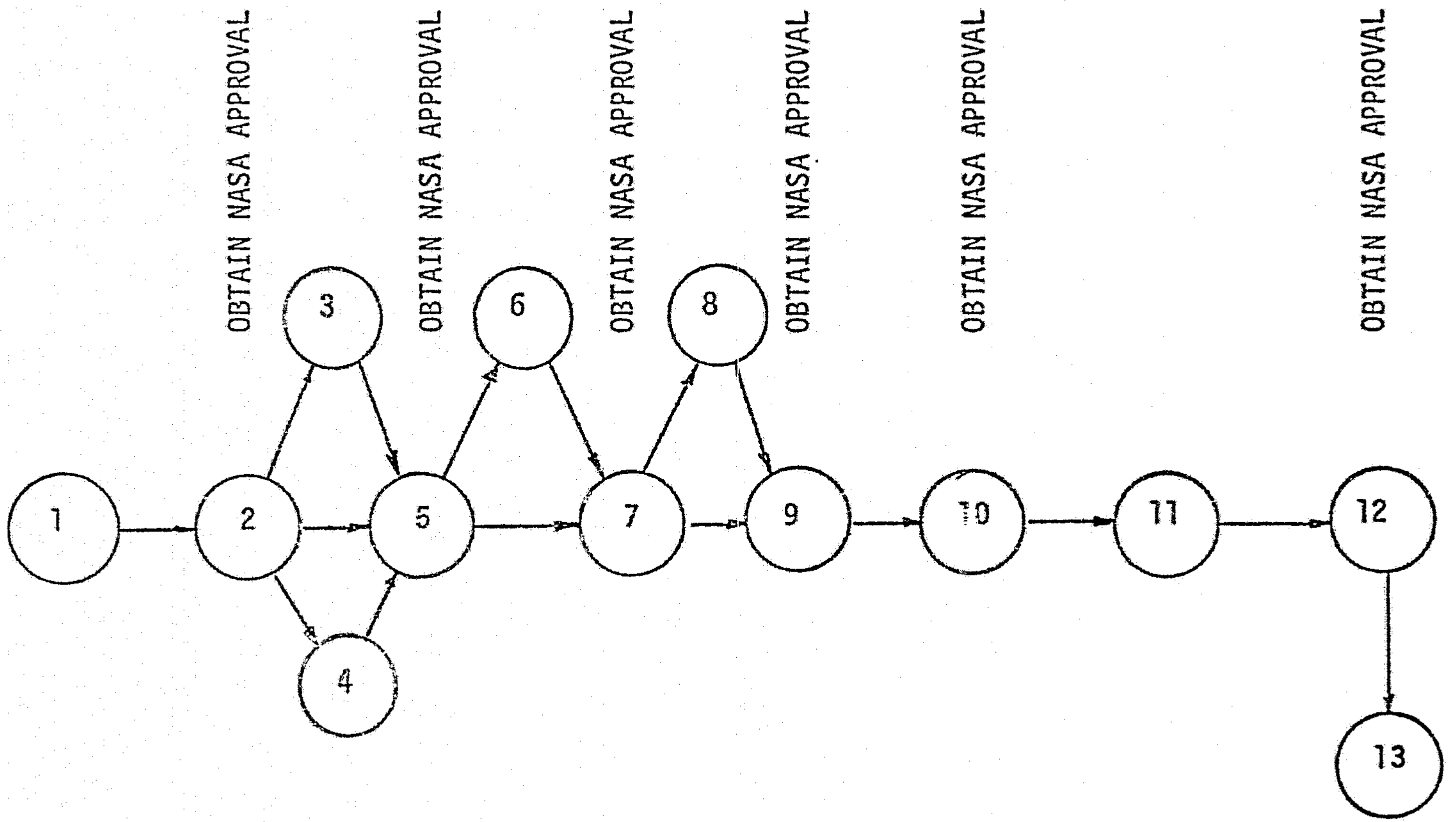
8.3 Method of Experiment Acquisition

A number of major tasks associated with the preliminary design of an experiment to study the solidification of materials under a zero gravity environment can be completed under the present grant. These tasks include (i) review and critical evaluation of the technical literature, (ii) establishment of contact with NASA personnel having an active interest in the proposed experiment, (iii) establishment of contact with NASA personnel capable of providing most recent information concerning experiment hardware components (power pack, timer systems, etc.), and (iv) completion of preliminary design study including selection of design concepts, selection of materials, definition of range of experimental conditions, summary of thermal, mechanical and physical property data for test and hardware materials and accurate assessment of power requirements.

The initial activity as shown in the Project Schedule, (Figs. 7 & 8) will be the overall design of the major subsystems or modules. Design concepts, including alternative schemes, for the power, timing and heater modules will be developed and submitted to NASA-Langley Research Center for review and approval. After approval of the design concept details of the actual power, timing and heater modules will be developed and again submitted to NASA-Langley Research Center for review and approval. Once approval is obtained, final drawings and detailed specifications will be prepared and submitted for final review and approval. By maintaining close cooperation between NASA-Langley Research Center and North Carolina State University it is believed that suggestions can be easily incorporated into the design and the need for radical changes avoided.

After review of the final drawings and specifications, the experimental package will be fabricated in the Precision Workshop of the Engineering Research Services Division of the School of Engineering at North Carolina State University. Personnel in the workshop have had extensive experience in the fabrication of sophisticated and specialized pieces of research equipment. If a need arises for change in either the design or specifications of the experiment during fabrication then approval will be sought from NASA-Langley Research Center prior to their execution. Concurrent with the fabrication of the experiment detailed test plans and procedures for experiment qualifications will be developed and submitted to NASA-Langley Research Center for approval.

At the present time it is planned to test the experimental package in the Department of Mechanical and Aerospace Engineering at North Carolina State University. Perhaps the most difficult tests to devise are those relating to the extremely high noise levels ($\sim$ 150 Db) and intense vibration to which



1 Start
2 Overall design complete
3 Detail design of sample module complete
4 Detail design of timer module complete
5 Detail design of power module complete
6 Hardware component procurement complete
7 Final drawings and specifications prepared
8 Test program design complete
9 Experiment fabrication complete
10 Experiment testing complete
11 Test analysis and experiment modification complete
12 Final checkout and modification complete
13 Deliver Experiment to Langley Research Center

FIGURE 7. PROJECT PLAN.

TASKS	TIME: Year One	Year Two	Year Three	Year Four
1. Overall Design of Experiments	xx xx xx xx			
2. Detail Design of Sample Module	xx xx xx xx			
3. Detail Design of Power Module	xx xx xx xx			
4. Detail Design of Timer Module	xx xx xx xx			
5. Hardware Component Procurement	xx xx xx xx			
6. Prepare Final Drawings	xx xx			
7. Fabricate Experiment		xxxx xxxx		
8. Conduct Test Program		xx xx		
9. Test Analysis and Modification		xx xx xx xx		
10. Final Checkout and Calibration		x x x x	x x x x	
11. Deliver Experiment to NASA LaRC			x x x x	
12. NASA Review	x x x x x x x x x	x x x x x x	x x x	
13. Post Flight Analysis				xx xx xx

Project schedule may be expanded or contracted to meet NASA requirements by a change in effort.

FIGURE 8. PROJECT SCHEDULE

the experimental package will be exposed during launch. However, the noise and vibration profiles given in the Users Guide have been discussed with Dr. F. D. Hart, Director of the Center for Acoustical Studies at North Carolina State University and he has agreed to assist in the design of a siren to obtain the appropriate noise levels and in the programming of a shaker table to generate the appropriate vibration profile. In addition, the experiment will be tested in the high vacuum system in the Department of Mechanical and Aerospace Engineering. This facility is capable of maintaining an environment of 10^{-8} Torr. After each of the devised tests the experimental package will be tested thoroughly through its complete cycle. It is planned to gather extensive qualification test data and postqualification data of tested experimental package. This data and appropriate analyses will be submitted to NASA-Langley Research Center for approval. It is hoped that NASA-Langley Research Center personnel will be able to visit the University to witness the qualification tests.

At the present time these authors are not aware of any experiments similar to that proposed which are being considered for inclusion of the LDEF mision. However, it is planned to maintain close communication with the LDEF project office so that should such experiments appear, then contact can be made with the appropriate investigator quickly with a view to the establishment of a cooperative effort to avoid possible unnecessary duplication.

Support will be required to integrate experimental package into the LDEF. However, all that is necessary is to bolt the package to the appropriate tray.

Every effort will be made to assure that the experimental package is safe such that it will not pose any threat to either the shuttle craft or

shuttle crew. Wherever possible, age hardened aluminum alloy (6061) and stainless steel will be used as structural materials. In addition, an attempt will be made to select test materials which are chemically inert, nontoxic and noncorrosive. The experimental package itself will be designed to withstand the temperatures, pressures, and mechanical and acoustical vibrations outlined in the LDEF Users Guide with an adequate factor of safety. The test program will verify the reliability of the experimental package to withstand simulated flight conditions In addition, the experimental package will be sealed in an aluminum alloy container designed to remain intact even under the most severe impact (crash) conditions.

8.4 Facilities and Equipment

As stated in Section 5 2 above a straightforward engineering design effort is required to select materials and to design the timer and heater/power modules Familiar, well characterized materials, designs and components will be used. Adequate facilities exist on the campus at North Carolina State University to design, fabricate and test the experimental package. In addition, adequate well known standard diagnostic techniques will be used for post flight data analysis All necessary equipment for the conduct of the analysis exists also on the campus at North Carolina State University Equipment or special facilities from NASA and other government agencies is not required

8 5 Cost Estimation

The completion of an experimental package suitable for flight aboard an early space shuttle mission involves several well defined functions which include design, hardware testing, integration and data evaluation. A tentative cost analysis based on these categories is given in Figure 9.

FUNCTION	ESTIMATED COST
Design	$ 25,000.00
Hardware	12,000.00
Testing	22,000.00
Integration Costs	8,000.00
Data Evaluation	20,000.00
TOTAL COST	$ 87,000 00

FIGURE 9. COST ANALYSIS

9. SUMMARY

The present report gives a statement of work carried out under National Aeronautics and Space Administration Grant NSG 1136 entitled "Long Duration Exposure Facility (LDEF) Experiments for Early Space Shuttle Missions".

The preliminary design of two simple experiments is given. The objectives of the experiments are to determine the effect of an absence of gravity on (i) the general morphology of the structure, (ii) location of ullage space and (iii) magnitude of surface tension driven convection, during solidification of several metallic and nonmetallic systems. Details of the investigative approach, experimental procedure, experimental hardware, data reduction and analysis and anticipated results are given. In addition a time based work plan and estimate of total cost is provided.